

Chlorophyll-a as a predictor of Biochemical Oxygen Demand in an urban lake: A case study in Samarinda, Indonesia

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ABSTRACT

Rapid methods for estimating biochemical oxygen demand (BOD) directly in the field are essential for improving the efficiency of water quality monitoring and environmental management. This study was carried out at Polder Air Hitam Lake, Samarinda City, from September to November 2023. Field measurements were conducted every two weeks over five sampling periods to determine chlorophyll-a concentrations and key water quality parameters, including dissolved oxygen (DO), pH, temperature, total dissolved solids (TDS), and turbidity. Water samples were also collected and analyzed in the laboratory using the standard five-day incubation method to determine BOD₅ values. The results indicated that chlorophyll-a concentration influenced oxygen consumption through algal respiration and decomposition processes. A relatively strong relationship was observed between chlorophyll-a concentration and BOD₅ across the five observation stations throughout the study period ($R^2 = 0.78$), while the correlation between chlorophyll-a and BOD₅ at individual stations was weaker ($R^2 = 0.32$). Higher BOD₅ values reflected greater oxygen demand associated with the decomposition of dead algal biomass. Variations in chlorophyll-a and BOD₅ measurements were also affected by environmental conditions, including pH, temperature, rainfall, and turbidity, which can influence fluorescence-based chlorophyll-a readings under field conditions.

INTRODUCTION

Biochemical Oxygen Demand (BOD) is one of the most widely used indicators for assessing surface water quality, as it reflects the readily biodegradable fraction of organic matter in a water body and provides information about the ready biodegradable fraction of the organic load in water. Conventional BOD determination relies on a standardized incubation period, typically five days (BOD₅) at 20 °C, during which the oxygen consumed by microorganisms decomposing organic matter is measured a method that is lengthy and requires a trained technician to obtain reproducible results, making it unsuitable for real-time monitoring of natural water environments such as rivers, streams, and ponds. Beyond the long turnaround time, conventional BOD₅ testing is also known to carry substantial measurement uncertainty, since results may vary between laboratories by as much as 20%, primarily due to differences in the microbial diversity of the inoculum used. These limitations restrict the usefulness of BOD₅ as an early-warning tool, particularly for urban aquatic systems where organic pollution levels can change rapidly in response to runoff, waste discharge, and human activity.

To overcome the time and reliability constraints of conventional BOD testing, several rapid, fluorescence-based approaches have been explored as surrogates for organic pollution assessment. Fluorescence techniques can detect readily biodegradable organic matter and have also been applied to determine *in vivo* chlorophyll-a concentrations rapidly, enabling identification of microbial communities in water and estimation of their correlation with BOD₅ (Hamdhani et al., 2021). This is ecologically plausible because phytoplankton biomass, commonly represented by chlorophyll-a concentration, is closely tied to the organic loading of a water body: the proliferation of phytoplankton is driven primarily by nitrogen and phosphorus discharged from industrial and urban waste, and organic matter parameters such as COD, BOD, total nitrogen, and total phosphorus have been shown to relate systematically to phytoplankton biomass as indicated by chlorophyll-a. Consistent with this, monitoring of urban lakes with contrasting trophic states has shown that chlorophyll-a, together with total phosphorus, COD, and BOD, responds similarly to environmental drivers such as precipitation and wind speed, with chlorophyll-a showing a significant positive correlation with nutrient concentration and temperature. These findings suggest that chlorophyll-a, as a proxy for algal biomass and primary productivity, may carry a predictable relationship with organic pollution indicators such as BOD (Jouanneau et al., 2014).

The potential to substitute or complement BOD₅ measurement with a rapid, *in vivo* chlorophyll-a estimate is particularly relevant for urban lakes, which are increasingly recognized as pollutant sinks under pressure from surrounding land use. Rapid urbanization has made urban lakes sinks for pollutants, with impervious surfaces shortening stormwater response times and increasing pollutant transport into the water body, while phytoplankton content is considered a key indicator of lake eutrophication because phytoplankton are the primary producers responding to nutrient status. If BOD can be estimated indirectly and rapidly from chlorophyll-a concentration using accessible fluorescence-based measurement, this would offer environmental managers and policymakers a practical early-warning tool for organic pollution, allowing near-real-time monitoring in place of a multi-day incubation test, a particularly valuable capability for densely populated urban catchments where water quality can deteriorate quickly (Basant et al., 2010).

Despite growing evidence of a relationship between chlorophyll-a and organic pollution indicators in lentic systems generally, site-specific studies confirming this relationship for tropical urban lakes, particularly those in rapidly developing Indonesian cities remain limited. Samarinda, as an urban center in East Kalimantan, hosts several urban lakes that receive substantial anthropogenic organic and nutrient loading, yet the extent to which chlorophyll-a concentration can serve as a reliable, rapid proxy for BOD in these systems has not been well established. This study therefore aims to determine the correlation between chlorophyll-a concentration and BOD values in an urban lake in Samarinda, with the broader objective of evaluating whether chlorophyll-a can be used to estimate or predict BOD levels as a faster and more cost-effective alternative to conventional BOD₅ testing in tropical urban aquatic environments.

METHODOLOGY

Study Area

This study was conducted from September to November 2023 at Air Hitam Polder Lake, Samarinda City, East Kalimantan Province, Indonesia. Laboratory analyses were carried out at the Water Quality Laboratory, Faculty of Fisheries and Marine Sciences, Universitas Mulawarman, Samarinda.

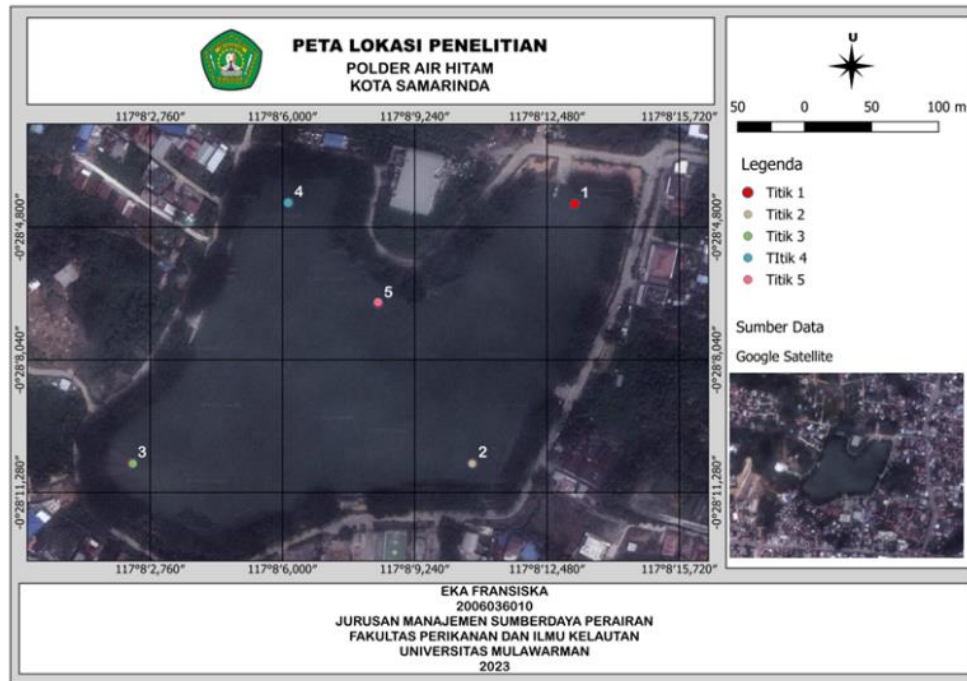


Figure 1. Map of the study area.

Instruments and Materials

The instruments and materials used in both field and laboratory activities are presented in Table 1.

Table 1. Instruments and materials used in the study

Instruments	Materials
Writing instruments	Distilled water (aquades)
Notebook	NaOH + KI solution
1.5 L sample bottles	H ₂ SO ₄
Fluorometer	Na ₂ S ₂ O ₃
Dissolved oxygen (DO) meter	MnSO ₄
Water quality checker	0.025 N K ₂ Cr ₂ O ₇
Turbidity meter	Starch indicator
Water dipper	Potassium iodide (KI)
Plastic cups	
Aerator	
Beakers	
Rubber bulb	
Volumetric pipettes	
Graduated cylinders	
Erlenmeyer flasks	
Burettes	
Weighing paper	
Analytical balance	

Bucket
Tissue paper
Winkler bottles

Water Quality Parameters

Water quality measurements were conducted at five sampling stations and included both primary and supporting parameters. The primary parameters investigated were chlorophyll-a concentration and biochemical oxygen demand (BOD₅). Supporting parameters included dissolved oxygen (DO), pH, temperature, total dissolved solids (TDS), and turbidity.

Research Procedures

Selection of Sampling Locations

Sampling locations were determined using a purposive sampling approach, in which stations were selected deliberately based on specific environmental considerations. Sampling was conducted five consecutive times at two-week intervals across five predetermined sampling stations. Station 1 was located at the inlet of the polder lake near the Samarinda City Government Workshop Warehouse, Station 2 was located near a school and the East Kalimantan Taekwondo Dojang sports facility, Station 3 was situated near the Samarinda branch of the Indonesian Red Cross (PMI), Station 4 was located adjacent to a residential area, and Station 5 was also situated near a residential area.

Sample Collection

Water samples were collected using 1.5 L sample bottles and transported to the laboratory for the determination of DO and BOD₅ concentrations. Chlorophyll-a and supporting water quality parameters, including dissolved oxygen, pH, temperature, TDS, and turbidity, were measured directly in the field (in situ). Chlorophyll-a concentration was measured using a FluoroSense® handheld fluorometer (Turner Designs, CA, USA). The same water samples were used for the measurement of the supporting water quality parameters.

Measurement of Primary Parameters

Determination of Chlorophyll-a Concentration

Chlorophyll-a concentration was measured in situ using a FluoroSense® handheld fluorometer (Turner Designs, CA, USA). The instrument performs in vivo chlorophyll analysis by detecting chlorophyll within living algal cells suspended in the water column. FluoroSense emits excitation light that stimulates chlorophyll-a fluorescence, and the resulting fluorescence signal is detected and converted into digital values that are correlated with chlorophyll-a concentration (µg/L).

Determination of Biochemical Oxygen Demand (BOD₅)

Each water sample was transferred into two 300 mL Winkler bottles labeled A and B. Bottle A was analyzed on the day of sampling, whereas Bottle B was stored in a dark, light-free container and analyzed after a 5-day incubation period. The Winkler titration procedure was performed by adding 1 mL of MnSO₄ solution and 1 mL of alkaline iodide solution to each bottle. The bottles were then sealed and inverted repeatedly until the solution was thoroughly mixed. After allowing the precipitate to settle for approximately 6–10 min, 1 mL of concentrated H₂SO₄ was added, and the solution was mixed again until the precipitate dissolved completely. An aliquot of 50 mL was transferred to an Erlenmeyer flask, and starch indicator was added prior to titration with standardized sodium thiosulfate (Na₂S₂O₃) solution. The volume of titrant used was recorded.

Dissolved oxygen concentration was calculated using the following equation:

$$DO_{(mg/L)} = \frac{V_{thio} \times N_{thio} \times 8000}{V_{sample}} \quad BOD_5 = (DO - DO_5)$$

where DO is dissolved oxygen (mg/L), BOD₅ is biochemical oxygen demand after 5 days (mg/L), *V_{thio}* is the volume of sodium thiosulfate titrant (mL), *N_{thio}* is the normality of sodium thiosulfate solution (0.0251 N), and *V_{sample}* is the sample volume (mL).

Data Analysis

The relationship between chlorophyll-a concentration and biochemical oxygen demand (BOD₅) in Air Hitam Polder Lake was evaluated using simple linear regression analysis. Statistical significance was assessed using the p-value, with $p < 0.05$ indicating a statistically significant relationship between the two variables. The coefficient of determination (R^2) was also examined to evaluate the strength of the relationship, with values approaching 1 indicating a stronger linear association.

To assess the water quality status of Air Hitam Polder Lake, the measured chlorophyll-a and BOD₅ values were compared with the applicable Indonesian water quality standards established under Government Regulation of the Republic of Indonesia No. 22 of 2021 concerning the Implementation of Environmental Protection and Management. The comparison was based on Class II water quality **criteria**, which apply to waters designated for water-based recreational activities and similar uses.

RESULT AND DISCUSSION

Primary and Supporting Water Quality Parameters

1. Primary Parameters

a. Chlorophyll-a

The chlorophyll-a concentrations measured in Air Hitam Polder Lake are presented in Table 2. Based on Table 2, chlorophyll-a concentrations in Air Hitam Polder Lake ranged from 23.0 to 168.67 µg/L. The elevated chlorophyll-a concentrations observed during the fifth sampling period were likely associated with a reduction in lake water volume resulting from seasonal weather changes, increased light intensity, and the influx of nutrients into the water body. Variations in chlorophyll-a concentration are influenced by several hydrological and physicochemical factors, including temperature, salinity, pH, and dissolved oxygen. Air Hitam Polder Lake can therefore be categorized as eutrophic, as chlorophyll-a concentrations exceeded 50 µg/L, the threshold value for Class II waters under the applicable Indonesian water quality standard. The green coloration of the lake further indicates the occurrence of phytoplankton blooms.

Table 2. Chlorophyll-a concentration in Air Hitam Polder Lake

Date	Chlorophyll-a (µg/L)					Water Quality Standard (Government Regulation of the Republic of Indonesia No. 22 of 2021, Class II)
	Station 1	Station 2	Station 3	Station 4	Station 5	
7-Sep-23	45	23.33	24.33	47.67	28.33	50 µg/L
20-Sep-23	56.67	25.67	23	36	36.33	50 µg/L
4-Oct-23	100.33	29.33	31.67	25.33	54.33	50 µg/L
18-Oct-23	90.33	155.67	37.33	51.33	46.33	50 µg/L
1-Nov-23	62	39.33	56.67	168.67	87.33	50 µg/L

b. Biochemical Oxygen Demand (BOD)

The measured biochemical oxygen demand (BOD₅) values are presented in Table 3. Laboratory analysis showed that BOD₅ values ranged from 0.16 to 2.72 mg/L. These concentrations remained within the permissible limits established by Government Regulation of the Republic of Indonesia No. 22 of 2021 for Class II waters. The relatively higher BOD₅ values recorded at Stations 2 and 4 were likely attributable to increased decomposition of organic matter in these areas. According to Djoharam (2018), higher BOD values indicate poorer water quality because greater amounts of dissolved oxygen are consumed by microorganisms during the decomposition of organic matter, resulting in oxygen depletion that may adversely affect aquatic organisms.

Table 3. Biochemical Oxygen Demand (BOD₅) in Air Hitam Polder Lake

Date	Biochemical Oxygen Demand (mg/L)					Water Quality Standard (Government Regulation of the Republic of Indonesia No. 22 of 2021, Class II)
	Station 1	Station 2	Station 3	Station 4	Station 5	
7-Sep-23	2.21	1.66	1.27	1.18	1.45	3 mg/L
20-Sep-23	1.6	2.2	0.68	1.32	0.32	3 mg/L
4-Oct-23	1.37	1.68	0.88	1.51	1.44	3 mg/L
18-Oct-23	2.07	3.1	0.16	2.05	2.16	3 mg/L
1-Nov-23	2.12	2.72	2.2	2.72	2.48	3 mg/L

2. Supporting Parameters

a. Dissolved Oxygen (DO)

The dissolved oxygen concentrations measured in Air Hitam Polder Lake are presented in Table 4. Dissolved oxygen is essential for the respiration and metabolic processes of aquatic organisms and is also required by microorganisms involved in the decomposition of organic matter. DO concentrations in Air Hitam Polder Lake ranged from 4.80 to 9.78 mg/L. According to the applicable water quality standards, all measured values exceeded the minimum Class II criterion of 4 mg/L, indicating that dissolved oxygen concentrations were generally adequate. Sinaga et al. (2016) reported that dissolved oxygen plays a crucial role in respiration, growth, reproduction, microbial metabolism, and organic matter decomposition in aquatic ecosystems.

Table 4. Dissolved oxygen concentration in Air Hitam Polder Lake

Date	Dissolved Oxygen (mg/L)					Water Quality Standard (Government Regulation of the Republic of Indonesia No. 22 of 2021, Class II)
	Station 1	Station 2	Station 3	Station 4	Station 5	
7-Sep-23	9.2	7.9	7.9	9.36	8.52	4 mg/L
20-Sep-23	6.99	7.35	7.68	9.16	6.33	4 mg/L
4-Oct-23	4.85	9.78	7.17	6.44	6.17	4 mg/L
18-Oct-23	4.8	8.58	7.85	7.33	5.92	4 mg/L
1-Nov-23	4.97	8.57	9.35	9.3	7.24	4 mg/L

b. pH

The measured pH values are presented in Table 5. The pH of a water body is an important indicator of water quality because it influences nutrient availability and microbial activity. Highly acidic waters generally contain lower dissolved oxygen concentrations and may increase respiratory stress on aquatic

organisms (Mudeng, 2019). The pH values measured in Air Hitam Polder Lake ranged from 7.74 to 9.97. Based on Government Regulation No. 22 of 2021, the lake water was generally alkaline but remained relatively close to the acceptable range for Class II waters. Elevated pH values may be associated with domestic wastewater inputs, particularly detergent-containing household effluents entering the lake.

Table 5. pH values in Air Hitam Polder Lake

Date	pH					Water Quality Standard (Government Regulation of the Republic of Indonesia No. 22 of 2021, Class II)
	Station 1	Station 2	Station 3	Station 4	Station 5	
7-Sep-23	9.38	9.38	9.15	9.53	9.36	6–9
20-Sep-23	9.09	9.05	8.88	9.08	8.69	6–9
4-Oct-23	7.74	9.51	9.37	9.25	9.52	6–9
18-Oct-23	8.14	9.97	9.76	9.82	9.29	6–9
1-Nov-23	8.21	9.68	9.5	9.57	9.23	6–9

c. Temperature

Water temperature measurements are presented in Table 6. In general, biological activity increases with increasing temperature, although excessive temperature elevations may stress or even cause mortality in aquatic organisms (Kordi and Andi, 2009). Temperature also affects the solubility of oxygen in water. According to Boyd, cited in Karu (2000), water temperature is influenced by solar radiation intensity, weather conditions, cloud cover, and water mixing processes. Temperatures in Air Hitam Polder Lake ranged from 27.7 to 31.5°C, which falls within the acceptable range of 27–33°C specified by Government Regulation No. 22 of 2021.

Table 6. Water Temperature (°C) in Air Hitam Polder Lake

Date	Temperature (°C)					Water Quality Standard (Government Regulation of the Republic of Indonesia No. 22 of 2021, Class II)
	Station 1	Station 2	Station 3	Station 4	Station 5	
7-Sep-23	29.3	31.1	30.2	29.9	29.6	±3°C from natural conditions
20-Sep-23	28.9	29.7	29.7	29.3	28.7	±3°C from natural conditions
4-Oct-23	29.4	31.5	30.1	30.2	29.5	±3°C from natural conditions
18-Oct-23	28.6	30.9	30.4	29.9	29.5	±3°C from natural conditions
1-Nov-23	27.7	31.5	29.9	28.9	28.1	±3°C from natural conditions

d. Total Dissolved Solids (TDS)

TDS measurements are presented in Table 7. The measured TDS values ranged from 169 to 314 ppm. These concentrations were well below the Class II water quality limit of 1,000 ppm established by Government Regulation No. 22 of 2021, indicating that dissolved solid concentrations remained within acceptable limits. According to Rinawati et al. (2016), the primary sources of TDS in aquatic systems include agricultural runoff, domestic wastewater, and industrial discharges.

Table 7. Total dissolved solids in Air Hitam Polder Lake

Date	Total Dissolved Solids (ppm)					Water Quality Standard (Government Regulation of the Republic of Indonesia No. 22 of 2021, Class II)
	Station 1	Station 2	Station 3	Station 4	Station 5	
7-Sep-23	176	176	176	174	175	1,000 ppm
20-Sep-23	180	178	179	180	181	1,000 ppm
4-Oct-23	314	170	174	186	169	1,000 ppm
18-Oct-23	274	185	185	187	185	1,000 ppm
1-Nov-23	212	200	216	205	206	1,000 ppm

e. Turbidity

Turbidity measurements are presented in Table 8. Turbidity results from the presence of suspended and dissolved organic and inorganic materials, including fine sediments, colloidal particles, and plankton, all of which reduce water transparency (Davis and Cornwell, 1998). High turbidity decreases light penetration into the water column, thereby limiting phytoplankton photosynthesis and reducing primary productivity (Mustofa, 2015). Reduced photosynthetic activity may subsequently decrease dissolved oxygen concentrations. Turbidity in Air Hitam Polder Lake ranged from 40.78 to 165 NTU. According to Hasniar (2014), turbidity values exceeding 50 NTU are considered high, while values above 25 NTU may already have adverse effects on aquatic biota.

Table 8. Turbidity in Air Hitam Polder Lake

Date	Turbidity (NTU)					Water Quality Standard (Government Regulation of the Republic of Indonesia No. 22 of 2021, Class II)
	Station 1	Station 2	Station 3	Station 4	Station 5	
7-Sep-23	53	61	61	53	54	50 NTU
20-Sep-23	49.09	46.02	45.4	42.21	40.78	50 NTU
4-Oct-23	128	60	66	75	68	50 NTU
18-Oct-23	165	118	83	84	89	50 NTU
1-Nov-23	129	69	104	71	61	50 NTU

Relationship Between Chlorophyll-a and Biochemical Oxygen Demand

The relationship between average chlorophyll-a concentration and BOD5 was evaluated using simple linear regression analysis to determine the correlation between these two variables.

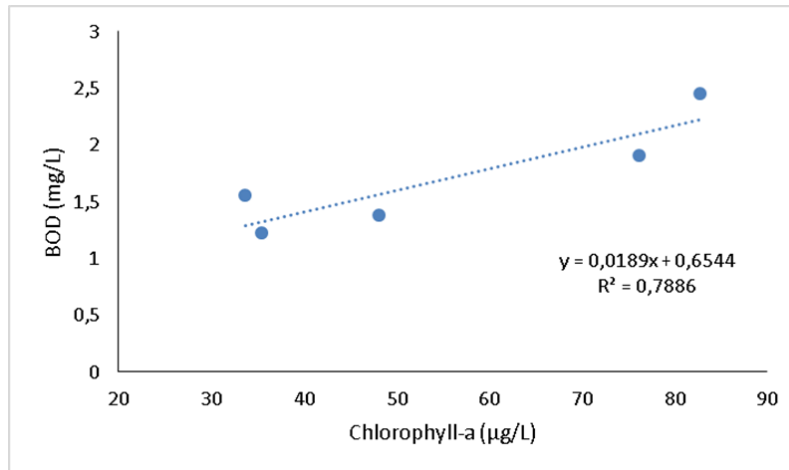


Figure 2. Relationship between chlorophyll-a concentration and BOD5 at the five sampling stations

For the station-based analysis, average chlorophyll-a and BOD5 values were calculated for each station across the five sampling periods. The regression analysis produced a **p-value of 0.044**, which is less than 0.05, indicating a statistically significant relationship between chlorophyll-a concentration and BOD5. The coefficient of determination (**$R^2 = 0.7886$**) indicates a **strong positive relationship** between the two variables.

Table 9. ANOVA results for the regression between chlorophyll-a concentration and BOD5 (five stations)

Source	df	SS	MS	F	Significance F
Regression	1	0.753616967	0.753616967	11.19238476	0.044206279
Residual	3	0.201999033	0.067333011	—	—
Total	4	0.955616	—	—	—

The positive relationship indicates that higher chlorophyll-a concentrations are associated with greater biochemical oxygen demand. Increased phytoplankton biomass ultimately undergoes decomposition, a process that consumes dissolved oxygen and contributes to oxygen depletion in the water column. Dissolved oxygen is essential not only for aquatic organism respiration but also for various chemical and biological processes occurring within aquatic ecosystems.

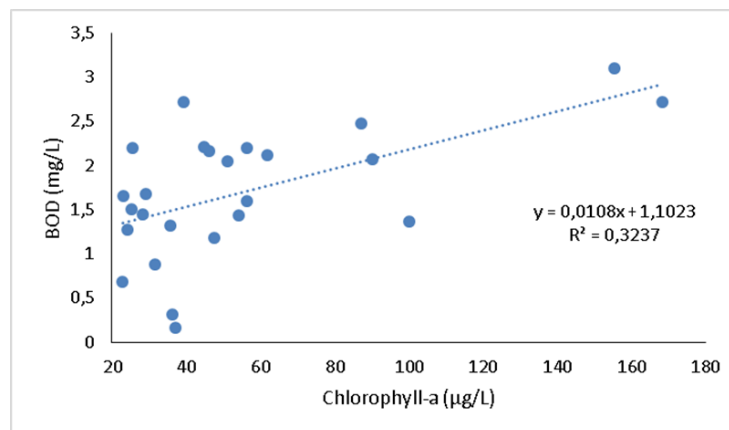


Figure 3. Relationship between chlorophyll-a concentration and BOD5 using all observations

When all observations from the five stations and five sampling periods were included in the analysis, the regression yielded a p-value of 0.002, indicating a statistically significant relationship between chlorophyll-a concentration and BOD5. The coefficient of determination ($R^2 = 0.3237$) suggests a moderate positive relationship between the two variables.

Table 10. ANOVA results for the regression between chlorophyll-a concentration and BOD5 (all observations)

	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	1	4,186759428	4,186759428	11,01093376	0,002995424
Residual	23	8,745440572	0,380236547		
Total	24	12,9322			

The observed positive relationship suggests that the investigated urban shallow lake supports abundant phytoplankton biomass. According to Beutler et al. (2002), higher chlorophyll-a concentrations reflect greater phytoplankton biomass, whereas lower concentrations indicate lower phytoplankton abundance. The relationship between chlorophyll-a concentration and BOD5 is likely driven by phytoplankton decomposition, which requires substantial dissolved oxygen and consequently increases BOD5 values.

Similar positive relationships between chlorophyll-a concentration and biochemical oxygen demand have been reported for several eutrophic shallow lakes in subtropical regions (Xu and Xu, 2015). Studies conducted in Lake Taihu, China by Wang et al. (2007) and Zhang and Qin (2001) also demonstrated positive correlations between phytoplankton biomass and BOD. Xu and Xu (2015) reported a correlation of $R^2 = 0.76$ between chlorophyll-a concentration and BOD in University Lake, Louisiana, USA. These findings indicate that chlorophyll-a can provide a relatively accurate estimate of BOD and may serve as a rapid and cost-effective approach for urban water quality monitoring. By incorporating chlorophyll-a measurements into real-time water quality monitoring systems, both chlorophyll-a concentration and BOD can potentially be estimated simultaneously without the need for extensive sample preparation or laboratory analysis.

CONCLUSION

Based on field observations conducted from September to November 2023, chlorophyll-a concentrations in Air Hitam Polder Lake ranged from 23.0 to 168.67 $\mu\text{g/L}$, while biochemical oxygen demand (BOD₅) values determined through laboratory analysis ranged from 0.16 to 2.72 mg/L.

According to Government Regulation of the Republic of Indonesia No. 22 of 2021, chlorophyll-a concentrations in Air Hitam Polder Lake exceeded the applicable water quality threshold, indicating that the lake is polluted and exhibits eutrophic conditions. In contrast, BOD₅ values remained within the permissible water quality standard for Class II waters.

Linear regression analysis produced coefficients of determination (R^2) of 0.7886 and 0.3237, respectively. The regression results demonstrated a statistically significant relationship between chlorophyll-a concentration and biochemical oxygen demand, indicating that chlorophyll-a concentration can be used as a rapid predictor of BOD₅. This rapid estimation approach has considerable potential for water resource management, particularly as an early warning tool for environmental pollution, enabling lake managers and environmental authorities to implement mitigation measures at an earlier stage and respond more effectively to water quality deterioration.

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